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TNF/S C3/D--TACNET: A MODEL OF THE ARMY'S TACTICAL COMMUNICATIO--ETC(U)
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

TACNET is an event-by-event simulation model of the European Army Tactical Networks, as represented in the 1974 INTACS EAD Study. Network junctions, relay stations, and command posts are included in the model, and they can be degraded in different ways. Messages are generated according to a call scenario, and a route is determined from tables or by a wider search, with provisions for preemption of lower priority calls. Statistics are gathered

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20. Abstract (Cont'd)

on the number of calls that are completed, preempted, or blocked; on the elapsed time to complete a call; on the number of links per call; on the utilization of command post personnel and queues of messages; and so on. Also, a series of messages that represent traffic associated with nuclear release is generated and evaluated separately. A network loading run was used as a starting point for a series of almost 100 runs of a network with different degrees of degradation. Results from these runs were used to find relationships between equipment degradation and communications degradation for communications both to and from division headquarters and for nuclear release messages. These functions were used elsewhere to represent command, control, and communications degradation in the theater-level war-gaming model TACWAR, which is being used in TRADOC's Theater Nuclear Force Survivability (TNF/S) program evaluation.

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FIGURES

1. INTRODUCTION

A number of tactical communications networks provide support to the U.S. Army in Europe in case of war. These networks are interconnected, and their combination is modeled by TACNET. In addition to the communications aspects of the model, there is a simple representation of command and control by delays in the processing of messages at the command posts.

TACNET is an event-by-event simulator written in the General-Purpose Simulation System (GPSS-V). Calls are individually represented by transactions, and they search for the trunks they need to reach their destination as a real call would do. Degradation of the network can be introduced after an initial period for the loading of calls, thus taking into account transient effects as well as a new steady-state configuration.

The war-gaming model TACWAR is being modified to include some command, control, and communications (C^3) effects and to show the consequences of degradation. Increased delays and a reduction in the number of messages that get through to their destination are determined from TACNET in terms of the severity of the degradation, and they are provided for incorporation into TACWAR.

2. NETWORK CONFIGURATION

The network represented in TACNET is formed by the 14 subnetworks that are shown as the INTACS EAD Baseline in the 1974 study.* These subnetworks show a varying degree of independence, but they are all interconnected. They go from the Theater Army and CENTAG through a corps slice down to the division level, including the Air Defense Artillery, PERSHING, and Tactical Air Force nets. The actual nodes represented go down to brigade level and, in some cases, to battalion level.

*Integrated Tactical Communications System Study, Martin Marietta Aerospace, 1975.

A hypothetical layout of the nodes is shown in the INTACS study and, for this model, the nodes were represented on a rectangular grid, neglecting the curvature of the Earth. The type of equipment associated with each link was identified, thus providing a basis for the assignment of a number of channels for each link.

The area covered by the network was divided into squares 10 km to a side, which were then used to represent the effects of enemy attacks on the nodes. Lists are kept that indicate what command posts, nodes, and links would be affected by a burst in a particular square. No movement of the nodes is considered in this model.

3. TACNET MODEL

This model is an event-by-event simulator of the tactical networks written in the GPSS language. The model runs on the Harry Diamond Laboratories (HDL) IBM 370/168 computer.

Each call is represented by a GPSS transaction characterized by an originator, a destination, and a priority. Originators and destinations are represented by storages of a capacity equal to the number of people preparing and processing the calls, and a delay time is assigned to each of these posts. Transactions queue up in order of priority when a storage is full. The call uses either of two routing tables to reach its destination, and where these routes are not available, a wider search for a route goes into effect. Each link is represented by entries in a matrix, and a record is kept of how many calls of each priority are using the link and how many channels are free. Switches are represented by delays, and information about the connectivity is found in savevalues.

When no channels are available to a priority call, it tries to preempt a call of lower priority. When preemption is not possible and no route is found to advance a call, this call is blocked. Preempted and blocked calls retry after a delay, and each call is allowed up to four tries.

Calls are generated from pairs of numbers (originator and destination) determined by a call scenario. The frequency of calls in each of five classes is established through the generation rate for transactions.

Degradation can affect the nodes, the links, and the command posts that process the calls, and, as the model is configured at present, the degradation is irreversible.

A number of FORTRAN programs are used to translate the information on the network and calls into INITIAL cards that are used in the GPSS model.

The amount of core required to run this model is 780 Kbytes, which does not present a problem on a virtual storage computer. The basic time unit chosen in the simulation is 1 s, and the Central Processing Unit (CPU) time required to simulate 1 hr of network activity is about 3 min. The GPSS SAVE/READ feature is used to save the configuration of the model after a run that serves to load the network, and several runs with different kinds of degradation can be performed, starting with the same initial conditions.

The output editor is used to select the information that is most likely to be useful in a run of TACNET.

3.1 *Call Scenario*

The originator, destination, and priority of each call generated in the model can be assigned at random, using the pseudo-random number generators provided by the GPSS compiler.

To generate a more realistic call scenario for this model, a set of standard calls was developed, taking into account Army doctrine on communications.* These calls are grouped into five classes, and the model assigns a different frequency to calls from each class. Calls within each class are selected at random, but a simple modification of the model could change this method to a more systematic use of the list. A different distribution of priorities is used for each of the five classes.

Some of the originators and destinations of calls are command posts that show an alternate within the network. When the main headquarters are flagged as inoperative, the generated calls are automatically changed to the corresponding alternate within this model.

A FORTRAN program is used to convert the information on the call scenario to the appropriate input cards for the GPSS model.

The model also can generate a special flow of messages in which an initial call results in further calls being sent down the chain of command and back up again if desired. Another FORTRAN program converts the information on the chain of calls into special transactions stored in a file that is then fed into the GPSS model through a JOBTAPE statement.

3.2 *Priority and Preemption*

The network represented in TACNET has the usual five levels of priority used by the U.S. in military communications, and each call is assigned a priority when the transaction is generated.

If a priority call finds no trunk available in a particular link, it preempts a call of a lower priority if one is present in the link. The call to be preempted is chosen at random among the lowest priority calls using the link.

Preempted calls are removed from all the links they have in use elsewhere in the network, and a retry is attempted after a delay. When a call is blocked, a retry is also attempted.

In this model, priority traffic is not affected by the presence of traffic of lower priority in the network.

3.3 *Routing*

At least one route was chosen for each call included in the scenario,† and a FORTRAN program is used to construct two routing tables to

**This part of the work was done by Thomas V. Noon.*

†Thomas V. Noon contributed to this part of the work

guide the calls through the networks. At each node on a route, a matrix element points to the link that should be used to get the call to the destination node. If a link is already selected that is different from the one being processed, the entry is made in a second matrix for an alternate route.

When a call first originates, it tries to follow the route indicated in the main routing table. If a link is not available to the call, it checks whether there is an alternate route. If neither is available, a search is conducted for the link with an available or pre-emptable trunk that gets the call closest to its destination. To avoid shuttling and "ring-around-the-rosie," a call is considered blocked if it tries to return to a switch it has already passed. If a call is on an alternate route, it first tries to continue on the alternate route and then checks the main route. At the start of the first retry, a call does not try the main route — to avoid, if possible, running into the same problem again.

The strategy for the link search is quite flexible, but it does not necessarily produce the best route. Actually, in some cases it leads a call into the wrong subnetwork, where it comes to a dead end because no direct connections exist to the destination. A less flexible strategy has also been tried, where a call is allowed to proceed as long as it can get closer to the destination. This procedure results in more blocked calls, but the average number of links per established call decreases. Other strategies for link searches can be devised and implemented in the model. A FORTRAN subroutine called by a HELP block has been found to reduce the running time of the model significantly when a degraded network leads to many route searches.

For a degraded network, where many links might be out, it is important to find a good routing strategy or an algorithm to update routing tables dynamically.

A special GPSS program was developed to determine whether calls that go on the JOBTAPE have at least a primary route in the table.

3.4 Network Degradation

To simulate the effect of combat on the communications network and, more specifically, the effect of nuclear attacks, the area covered by the network was divided into squares. The size of a side, 10 km, is somewhat larger than twice the radius where destruction of the equipment would follow the detonation of a tactical nuclear weapon.

Squares are selected at random to be hit by a nuclear weapon. The switches in that square and the links that terminate in the square or go over a relay in that square are taken out with a given probability. If all links to a switch are out, the switch and any collocated command post are also out of the network. Command posts can also be eliminated or degraded by decreasing the number of available personnel that handle the messages. The probabilities of link, node, and command post elimination and personnel reduction at a command post are given by savevalues and one variable.

When a switch or a link is hit, all calls that are using the affected links are interrupted, and they are allowed to retry after a delay, as if they had been preempted. These calls also appear in the different statistics as preempted calls. It is assumed that information about the elimination of a command post is known throughout the net after a given delay.

A more detailed scenario could be implemented in the model. The weapons used and the corresponding most likely targets could be identified, together with a more precise determination of the equipment in the affected area.

3.5 Output

The GPSS output editor is used to select those statistics that are meaningful as results from a run or that can help detect the occurrence of problems with the model. They include the clock statistics, the block counts, and selected savevalues. Tables are used to print the distributions of the times needed for a call to be completed, the number of tandem switches, priorities of preempted and blocked calls, terminal links that block calls, and the last switch for blocked calls. Also, statistics are kept on the staff utilization at command posts and the length of queues that can form there. Byte save-values are used to record the originator and destination of blocked calls. Also, a list of squares that are hit for a degradation run is provided.

Calls with multiple destinations and others that enter the model via a JOBTAPE statement are especially marked, and different types of information can be collected for them. The processing times for these calls are included in the total statistics, but they are also tabulated separately. A determination is also made of how many of these special messages fail to arrive within the simulated period.

There is also a special interest in calls originating and terminating at the division level. The total number of these calls that were completed during the period and the number of those that were abandoned after the allowed maximum retries are printed out.

4. INTERFACE WITH TACWAR

TACWAR is a computer model of the theater-wide war game that includes nuclear effects. It has virtually no direct representation of command, control, and communications and their influence on the outcome of a war. Modifications have been implemented* in several areas to include these aspects of military operations, and two of these specifically relate to the degradation of com-munications as modeled in TACNET.

One way to take this degradation into account is through an additional factor to the effectiveness of a division. The relationship between the physical degradation of the communications network and this effectiveness factor can be separated into two parts. The reduction in message flow is a function of the network degradation, but it is not simply proportional to it. This function can be estimated by using TACNET, and the results are discussed in the following section. The connection between the message flow and the effectiveness of a division is a complicated one, and depends upon factors such as the mission of the division, the state of the battle, and many others. At the level of detail achieved in TACWAR, some kind of average curve would be sufficient. Ideal communications would correspond to a factor of 1 with 0 degradation. With total degradation (1), there still would be some form of communication that does not use radios, such as messengers or telephone cables, and the division would still be able to function to some extent. To obtain an estimate of this residual effectiveness factor,† a model such as FOURCE could be used.

Command, control, communications, and combat effectiveness (FOURCE) is a division-level force-on-force combat model with resolution to battalion. This model was originally developed by the U.S. Army TRADOC Systems Analysis Activity for support of the Tactical Operations Systems (TOS) Cost and Operational Effectiveness Analysis (COEA). Subsequently, FOURCE has been used to support several other analysis efforts. This model contains a reasonably detailed representation of command and control.

Some existing runs of FOURCE indicate the influence of communications degradation on the outcome of a battle. These are mainly preliminary runs in which the objective of the division is to avoid a breakthrough by enemy forces. Runs were compared in which there was no degradation of communications; some degradation due to electronic warfare (EW) on FM nets, with and without wire communications; or no communications at all between maneuver units. From the output of these FOURCE runs (equipment losses, remaining viable units, and time to breakthrough, if any), and from discussions with other sources of information, a division effectiveness degradation factor interpolated by straight lines between the points (0,1), (0.3,0.95), (0.5,0.75) and (1,0.5) was chosen to express the relationship of this factor with division communications degradation. A more precise evalu-

*John C. Ingram, C³/D Modified TACWAR Model, Harry Diamond Laboratories report in preparation.

† This work was done with Alfred G. Brandstein.

ation of this function under different missions and circumstances is certainly desirable.

Although a composite of the two functions can be included in TACWAR, it is preferable to define them separately so that each can be improved as more information on the relationship becomes available.

A second area in which communications can be introduced in TACWAR is that of a nuclear strike. If nuclear release messages do not reach their destination, this operation fails. In TACNET, this activity is modeled by those special messages introduced from the JOBTAPE file, and a determination is made of the number of these messages that reach their destination. The corresponding fraction is given to TACWAR as a function of degradation to determine the number of nuclear weapons that are actually fired.

Other areas where C^3 degradation has a significant impact within the framework of TACWAR can be found, such as the timing of decisions related to the escalation process. Other information from TACNET runs could thus be used to improve the war-game model.

5. TACNET RUNS

A series of almost 100 "production" runs of TACNET was used to determine the degradation functions to be incorporated into TACWAR.

The final configuration of the model after a two-hour (simulated time) run of the undegraded network was saved to serve as the starting point for all other runs. Subsequent runs start with a general simultaneous degradation of the network, followed by the simulation of 1 hr of activity. The runs are grouped by the number of bursts that are selected, and in each case the seed was varied for the random number generator that controls the effects of the bursts.

A part of the output from TACNET was transferred to a FORTRAN program that produced two plots. The independent variable in both plots is the fraction of links that are out, which was chosen as a measure of network degradation. The first plot then shows the degradation in division communications, as measured by the fraction of messages to and from division headquarters that fail to arrive at their destination. The second plot shows the degradation in the arrival of special messages in a similar way.

5.1 *Input Parameters*

A large number of values have to be selected to represent the network load in the model.

The generation rates of calls of each class were set in such a way that the total number of calls generated in the 1-hr runs was about 6680. This corresponds to 30, 20, 15, 10, and 5 min between calls on the average for classes 1 to 5. The corresponding average call lengths were set to 600, 450, 300, 150, and 60 s, to obtain a reasonable load on the undegraded network. Shorter call lengths and intercall times could have been selected with similar effects on the network load, but the run time would have increased.

The processing time for incoming and outgoing calls was arbitrarily set at 5 min, and the personnel at the different command posts were chosen so that some queues would form under normal conditions, without their growing too large. A more realistic assignment could have been used for these quantities, but it was felt that there was no need in this particular case to invest the additional time.

The number of bursts was varied between 60 and 1100, the number of squares is 350, and multiple hits are allowed. The effects of a burst in a square are determined by probabilities that are set at each run. In all these runs, they were kept the same and, briefly,

(a) the attrition of personnel at a command post varied between one person and about 63 percent of the total,
(b) no junction nodes were taken out all at once,
(c) the probability for link survival was 80 percent,

(d) the probability of node attrition was 80 percent, and

(e) The probability that this attrition would be partial was 85 percent.

A total of 57 special messages are generated by transactions on a JOBTAPE. They generally follow the chain of command for nuclear release, and lower echelon messages are generated when the higher ones arrive.

5.2 Description of Results

As described in section 3.5, the output of the program includes a variety of tables and other GPSS statistics that allow an in-depth evaluation of each run. A few general remarks follow on some of the observed tendencies.

The damage to the network was widely scattered, as all squares had the same probability of being hit. As the command posts are taken out or degraded, the queues of messages at some of them grew significantly. Nevertheless, the average time a message took to be completely processed did not change much, probably because the load on the network is reduced by the degradation of command posts. Also, messages going between widely separated points in the network would not arrive at all. The average number of tandem switches per message at first increased slightly as the messages found more circuitous routes, but then fell when the degradation became more widespread and mostly short-route messages were completed.

5.3 Degradation Functions

Figure 1 shows the relationship between the degradation of the network as measured by the percentage of links that are out and the degradation of division communications. Different letters were chosen to represent runs of a group with the same

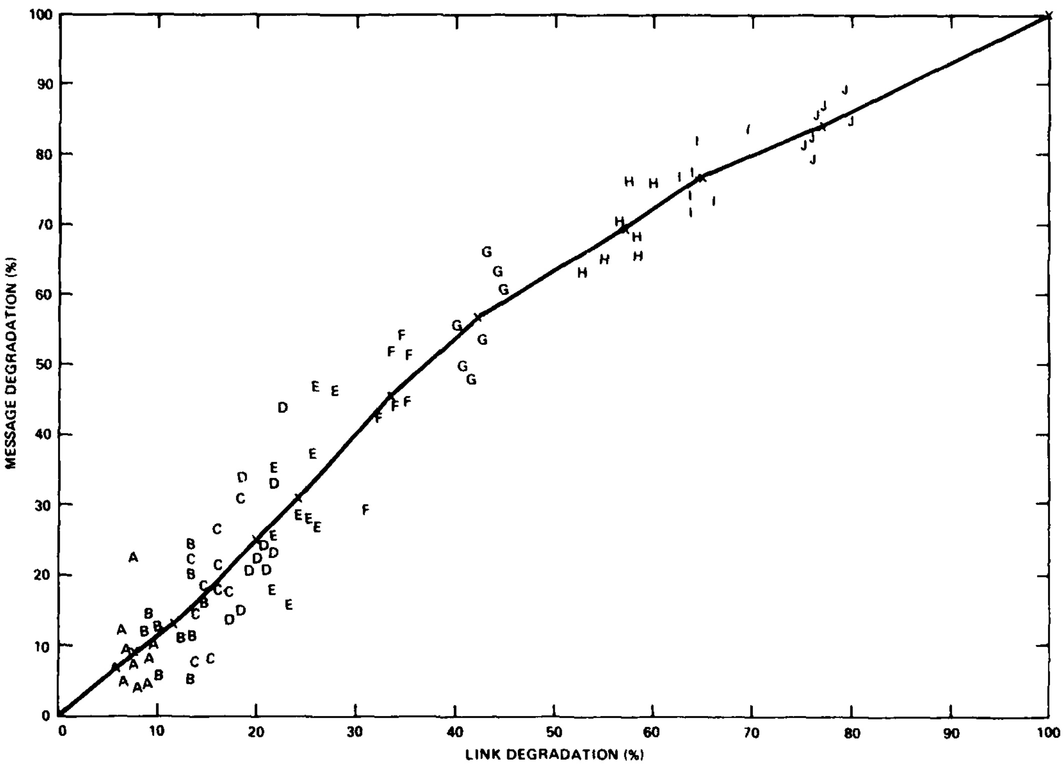

Figure 1. Degradation in division communications.

number of bursts; they are A(60), B(90), C(120), D(160), E(200), F(300), G(400), H(600), I(800), and J(1100). Each group is then reduced to the average point, marked by an X, and a line is drawn through these points.

A similar construction was made for the degradation in the arrival of special messages, as shown in figure 2. The link degradation is the same number for both graphs, but the dispersion in the values of message degradation is much larger in the second graph. This can be understood if one recalls that the number of special messages (57) is much smaller than that of division-level communications (about 1400) and that a chain of messages is susceptible to damage of the links used by the originator of the messages. A larger number of runs would give more valid results, but the increased precision is not required by TACWAR at present.

6. CONCLUDING REMARKS

Disruptions in the multichannel communications networks in Europe were modeled by TACNET to study the effects on the flow of messages.

The purpose of the series of runs described in this report was the inclusion of C^3 degradation into the theater-level war-gaming model, TACWAR. The changes in communications both at the division level and for nuclear delivery messages were determined in a broad average sense, appropriate to the spirit and configuration of TACWAR. As that model gets refined and more C^3 functions are explicitly included in it, corresponding refinements in TACNET can lead to more accurate and varied representations of C^3 degradation. Areas where improvements would be desirable include a scenario of nuclear attack on communications, specific

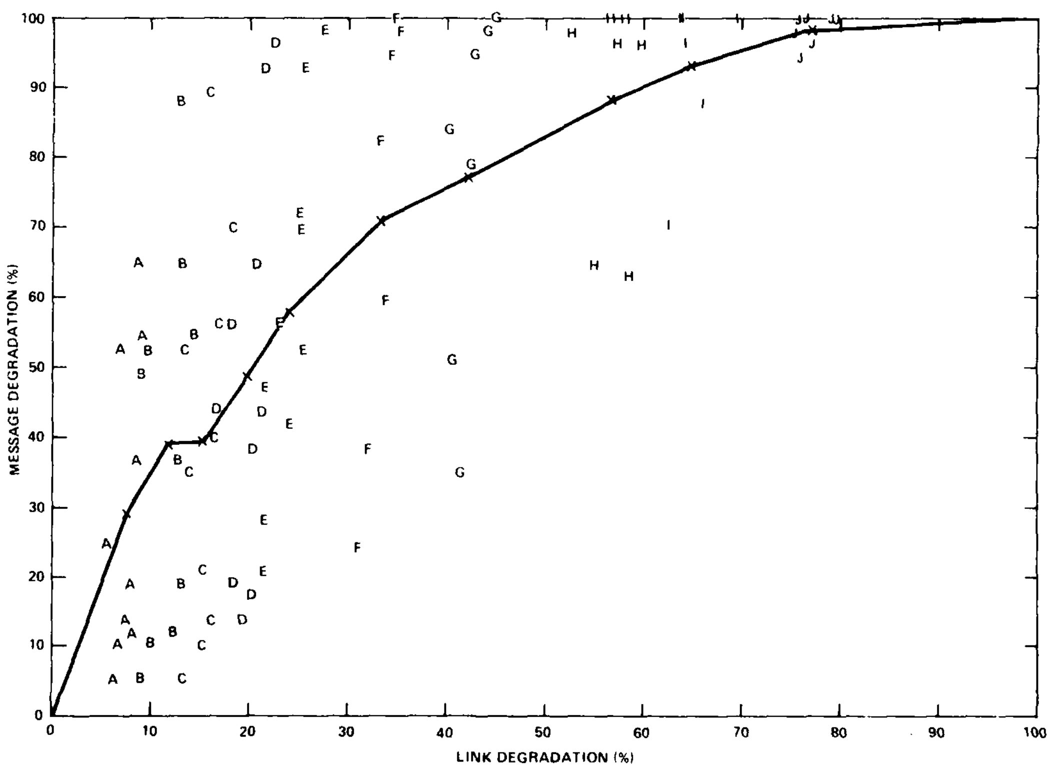

Figure 2. Degradation in special message arrival.

EW effects, better statistical representation of frequency and duration of calls, and a more accurate description of the personnel and processing times at command posts.

More generally, TACNET can be used to study the effects of the introduction of new equipment, to find the optimum distribution of equipment throughout the network, to test the effectiveness of different routing strategies, especially in the light of network degradation, and to check the grade of service under varying circumstances.

Other networks that serve functions similar to those presently included in TACNET can be added to the model, especially to give a more realistic representation of communication at levels of corps and above. Or a wider network of multichannel communications can be chosen as opposed to the corps slice presently modeled.

Thus, the successful use of TACNET to provide information on C^3 degradation to be included in TACWAR constitutes only a small sample of the different ways TACNET can be used.

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